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Roll-to-roll extrusion coating process for high-speed replication of micron-sized periodic patterns

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A recently developed method for producing micro-/nanostructures using roll-to-roll extrusion coating [1] shows great promises in terms of implementing the technology into the packaging industry. The method has been proven to produce various structures and in this study a more systematic approach is chosen, in order to support the further development of this technique.

During the extrusion coating process, the melted polymer is extruded through a flat nozzle directly onto the carrier foil (Figure2). The polymer is then pressed against the cooling roll, where it solidifies and sticks to the surface of the carrier foil. In the case of semi-crystalline polymers, during the replication process due to the supercooling the polymer can fill in the structures before it solidifies. The considered parameters for good replication fidelity are the crystallinity of the extruded polymer, the output and the line speed, the temperature of the cooling roll and the pressure on the cooling roll.

In this study the replication fidelity is tested using micro-sized pillars in different aspect ratios: 1:2, 1:1 and 2:1, within the range of 5-10 µm. The line speed, extrusion output, temperature of the cooling roll and the pressure (Figure2) are systematically varied and compared to each other in terms of the replication fidelity. Polypropylene is used as the extruded material. The filling factor is measured by scanning the surface of the produced polymer with an optical profilometer and the volume of the produced pillars is calculated by integrating the measured surface. A scanned image of the surface is shown in Figure 1.

The silicon master for pillars is produced by UV photolithography and DRIE etching, an SEM image of such a surface is shown in Figure 3. The pattern from the Si master is then covered with NiV and Ni is electroformed on top of the wafer. The excess silicon is then etched away using KOH. The produced nickel replica of the Si master is attached onto the cooling roll of the extrusion coater. After the extrusion coating process, the produced foils are covered with 20nm gold for easier SEM imaging. In Figure 4 an SEM image of such a produced foil is shown, the image can be directly compared to the Si master in Figure 3, where the replication fidelity of the produced pillars is close to 1.

The aim for the future studies is to examine the replication fidelity for various polymers. Knowing the best parameters for replication on the micro- and nano-scale, the two will be combined into hierarchical structures for superhydrophobic surfaces as in [3] and other functional structures. Potential use of this technology for the anti-counterfeit purposes is also considered.

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[2] S. Murthy, M. Matschuk, Q. Huang, N.K. Mandsberg, N.A. Feidenhans'l, P. Johansen, L. Christensen, H. Pranov, G. Kofod, H.C. Pedersen, O. Hassager, R. Taboryski, Adv. Eng. Mat., 18(4) (2016) 484-489.
[3] E. Søgaard, Injection molded self-cleaning surfaces, Ph.D. Thesis, Institute for Micro- and Nanotechnology, Technical University of Denmark, 2014.

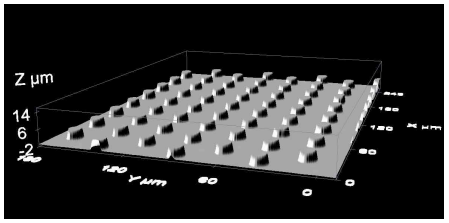

Figure 1. Surface of the replicated foil scanned with an optical profiler: calculating the average volume of each pillar helps determine the filling factor for the different parameter sets.

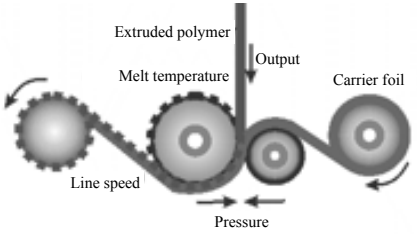

Figure 2. The schematics of the extrusion coating process and the important process parameters considered in this study

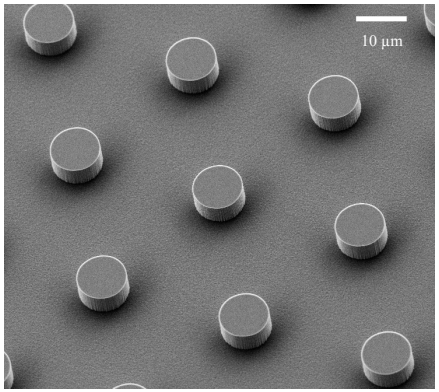

Figure 3. The original Si wafer produced using a DRIE process. The pillars are 10 µm in width and 5 µm in height. SEM image taken at 30° angle.

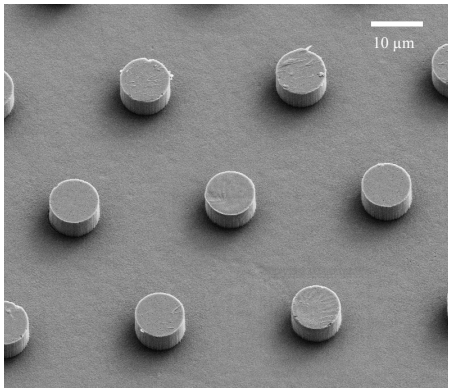

Figure 4. The pattern replicated in polypropylene using a Ni stamp. This set of parameters gave the filling factor close to 1.